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The Selection of Convertible Engines With Current Gas Generator Technology for High Speed Rotorcraft

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THE SELECTION OF CONVERTIBLE ENGINES WITH CURRENT GAS GENERATOR TECHNOLOGY FOR HIGH SPEED ROTORCRAFT

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ABSTRACT

Two NASA-Lewis sponsored studies were conducted to determine the most promising convertible engine concepts for high speed rotorcraft. These precursor studies projected year 2000 convertible technology, but were limited to current gas generator technology. The impetus behind these efforts was to insure that appropriate propulsion information would be available for the contracted High Speed Rotorcraft studies being conducted under the aegis of the NASA Ames Research Center.

In this presentation, the efforts of General Electric and Allison Gas Turbine are described. Propulsion systems were investigated for use on aircraft requiring thrust only at cruise and those aircraft requiring both power and thrust at cruise.

The aircraft and missions used for the comparisons are presented. The methods for engine selection and the basic characteristics of the selected engines are also presented. Differences in engines selected by the two contractors are explained.

In addition, the technology needs are identified along with suggested plans for more detailed follow-on studies, including those that address the use of high temperature, high pressure ratio gas generators utilizing technology expected to be available beyond year 2005.

BACKGROUND

CURRENT HIGH SPEED ROTORCRAFT

Many papers have been written over the years concerning rotorcraft with speed capability greater than 400 knots. Reference 1 is a typical example. Therefore, only enough description of the various high-speed rotorcraft concepts will be presented to define the requirement for convertible propulsion systems. The tilt rotor, figure 1, is currently a prototype, flying aircraft able to cruise at speeds greater than 300 knots for hundreds of miles carrying significant payload. To go much faster, over 450 knots, the rotor must either be stored or stopped and used as a wing, and a propulsion system able to operate efficiently at high speeds must be used - that is, a turbofan or propfan.

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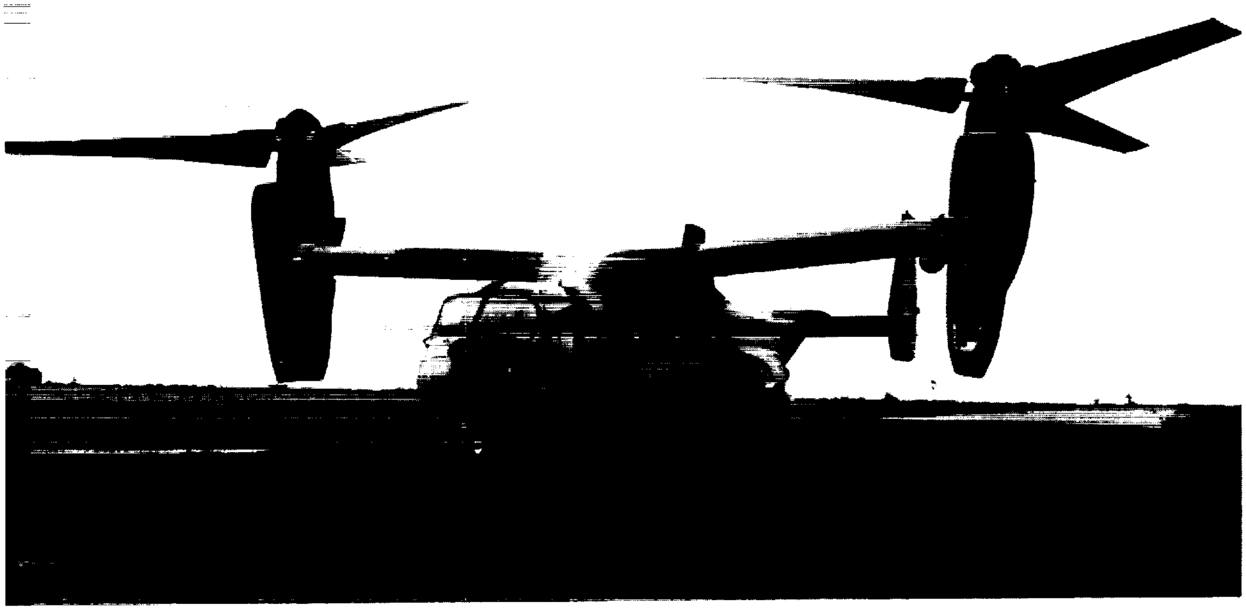

Figure 1. V-22, OSPREY TILT-ROTOR AIRCRAFT

ADVANCED HIGH SPEED ROTORCRAFT

There are many possible configurations that can be envisioned for a high speed rotorcraft. To illustrate their operation, a few of these aircraft will be addressed. In figure 2, a compound helicopter is depicted. The wings provide lift at high speed when the rotor speed is reduced. Additional propulsion is then applied. Here it is an aft mounted propeller. The next step, getting to the 450 knot speed, would be to fold the rotor and either trail it or stow it in a closed housing and go to turbofan or propfan propulsion. Figure 3 shows a folded-tilt rotor. Here the rotors are in the horizontal plane during vertical operation and tilt into the vertical plane for low speed cruise. Then the rotors are folded, stowed (they could also be trailed), and auxiliary turbofan or propfan propulsion is used to attain higher speeds. Lift is provided by the fixed wings during cruise. The two aircraft of figures 2 and 3 represent those that require shaft power only during vertical operation and thrust only during high speed cruise. Dual-mode operations are only required for very brief periods, merely to offer smooth conversion.

Figure 4 shows the X-wing concept. This aircraft uses its rotor for vertical lift and low speed cruise. The rotor is then stopped to form a cruciform wing, and auxiliary propulsion is applied. In order to keep rotor weight low, blowing through slots to take advantage of Coanda effect is used to provide additional lift. Since this blowing takes considerable power, the propulsion system must provide both shaft power and thrust simultaneously during cruise, and thus dual-mode operation is required at all times.

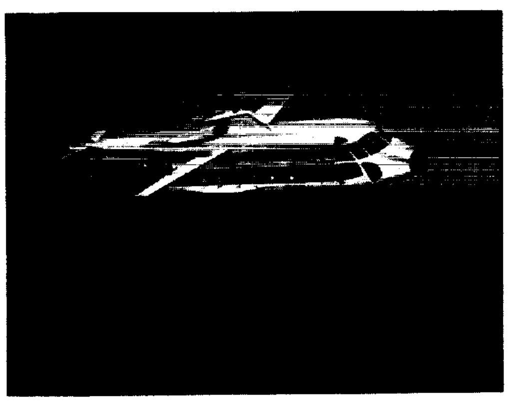

Figure 2. COMPOUND HELICOPTER

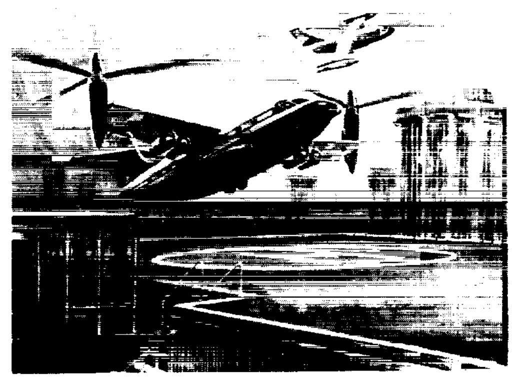

Figure 3. FOLDED TILT ROTOR AIRCRAFT

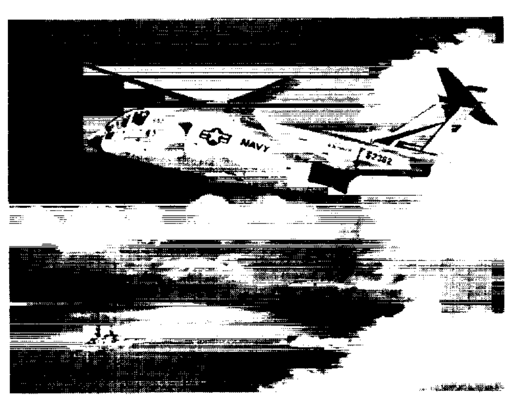

Figure 4. X-WING, STOPPED ROTOR AIRCRAFT

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CONVERTIBLE PROPULSION SYSTEM BENEFITS

There are two ways to power these high speed rotorcraft (HSRC). One is to have two sets of engines, one for shaft power and one for thrust (in a typical aircraft this would require four gas generators). The other is to have engines that operate in both modes as required. This would reduce the number of gas generators to two. In 1982, two contract studies were completed in which the potential improvements using these propulsion systems capable of both shaft and thrust operation (convertible propulsion systems) were estimated (Reference 2 and 3). The results were based on three aircraft flying different missions. They have been updated to reflect current costs and are presented in figure 5. The aircraft on the left is the advancing blade concept (ABC). Although its potential speed is far below that required in the NASA studies, it is included since it would benefit from a convertible system. In the bar chart, the improvements are illustrated. They are remarkably similar, roughly 15 to 20 percent. Although not shown, the fuel savings was about 15 percent. The improvements were due to the reduction in aircraft weight. The magnitude of these differences is such that it would be a determining factor in the economic viability of the HSRC. Therefore, separate engines are not considered for these aircraft.

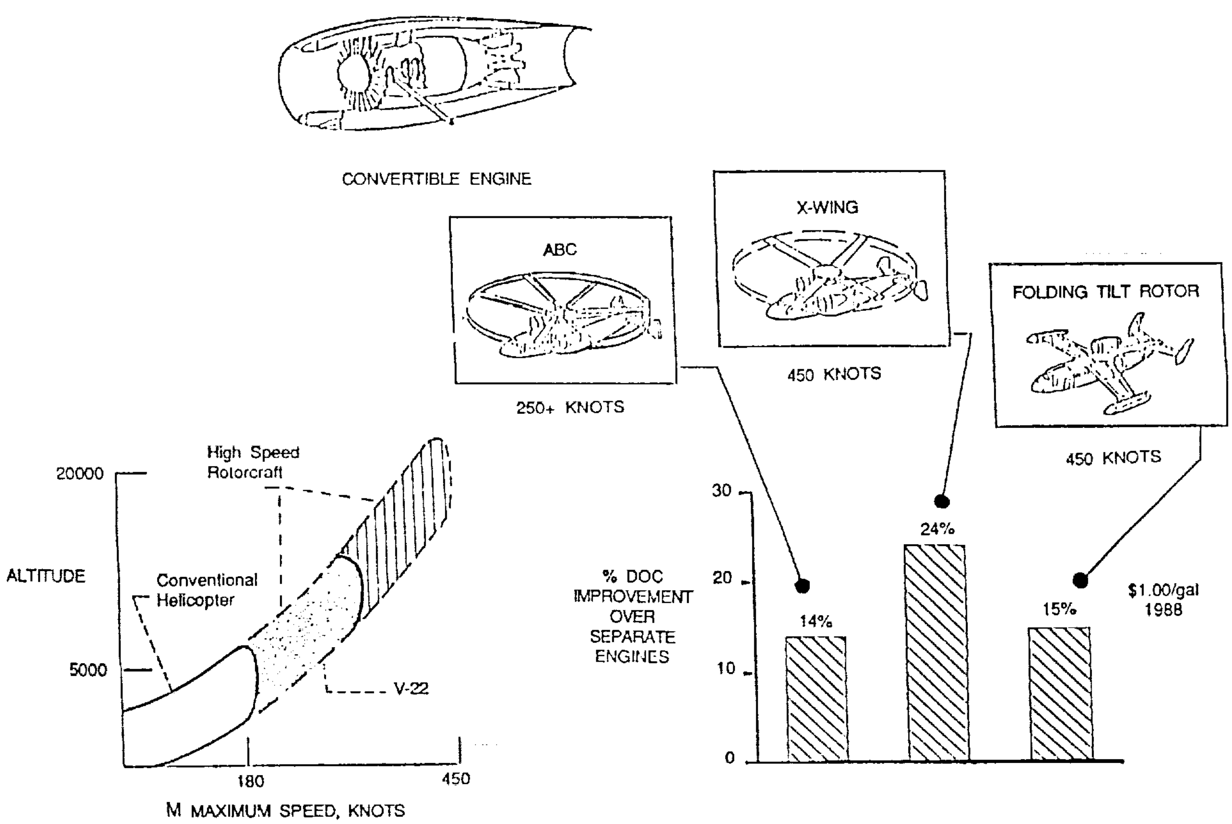

Figure 5. EARLY 1980's HIGH SPEED ROTORCRAFT PROPULSION STUDY RESULTS

CONVERTIBLE ENGINE CONCEPTS

In figure 6 are depicted several concepts for convertible systems.

With the variable inlet guide vane (VIGV) system, the guide vanes in the duct are closed during rotor operation. Although there are significant churning losses in the duct, the engine in this mode operates as a turboshaft engine. For cruise the vanes are open, and the engine is essentially a turbofan. For dual-mode operation with both power and thrust required, the vanes are positioned at some intermediate setting.

Two other systems with the capability to operate in the dual power and thrust mode are the variable pitch fan and the propfan. In principle, these work the same. When power is required, the pitch is set so that very little thrust is generated and nearly all energy goes into the shaft. When thrust is required, the pitch is changed so that the core energy is all used to furnish thrust. Intermediate pitch settings are used for combined power-thrust requirements.

With the gas diversion system, any combination of thrust and power is possible by opening and closing valves. The valves must be synchronized at all times to maintain proper back pressure in the system. Although not illustrated here, another gas diversion system possible is one that blocks or turns the flow by the use of nozzle variability.

The clutched fan system, which here is shown as a fluid coupling, is capable of power-thrust splits only during brief periods when changing from one mode of operation to the other. Here the fan is declutched during shaft operation and locked to the power turbine during cruise. The clutch is now envisioned as a torque converter, which is drained of all fluid except during transition between modes of operation. During cruise the fan is mechanically locked to the shaft.

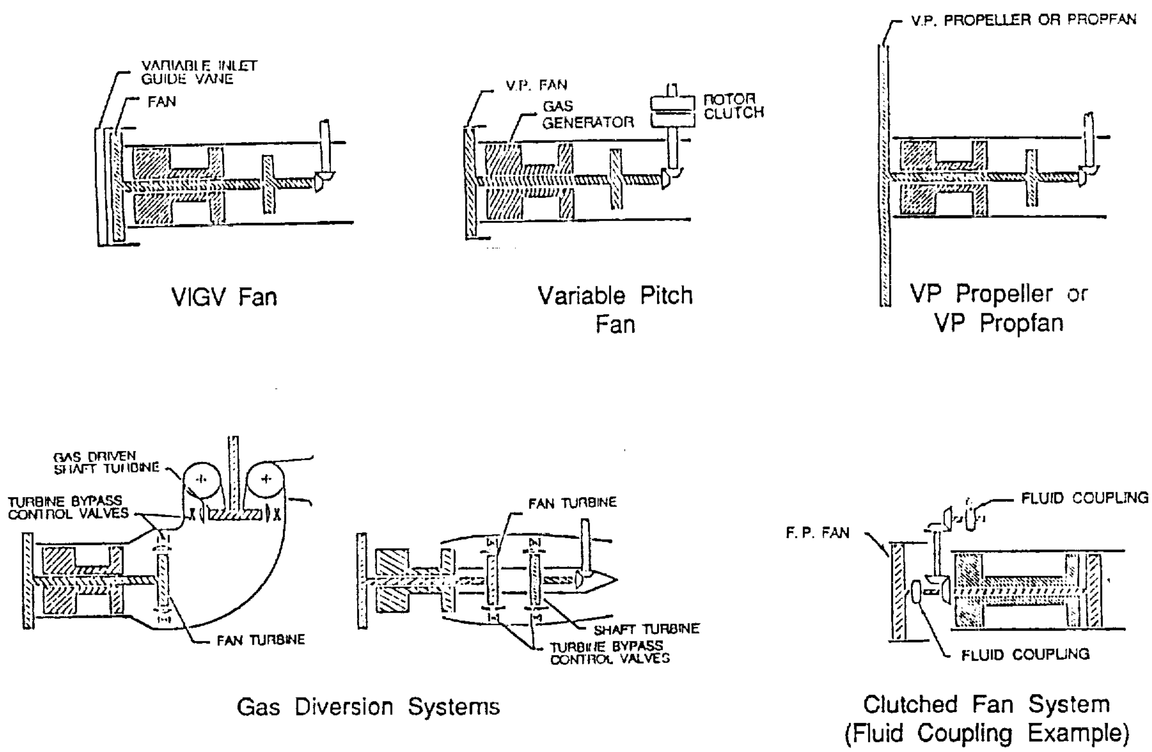

Figure 6. CANDIDATE CONVERTIBLE ENGINE SYSTEMS

CONVERTIBLE PROPELLER/SHAFT CONCEPT

An additional convertible system in which clutches and shafts are used to take power to rotors and remote propulsors is shown in figure 7.

This system with shafts to rotors, propellers, or remote fans simply ties in or releases the various systems as required. Here the gas generator is never supercharged, even during cruise operation with a turbofan. Considerable work has been done on applicable wet clutches. A clutch of this type was designed and built by Allison for use with an X-wing rotor.

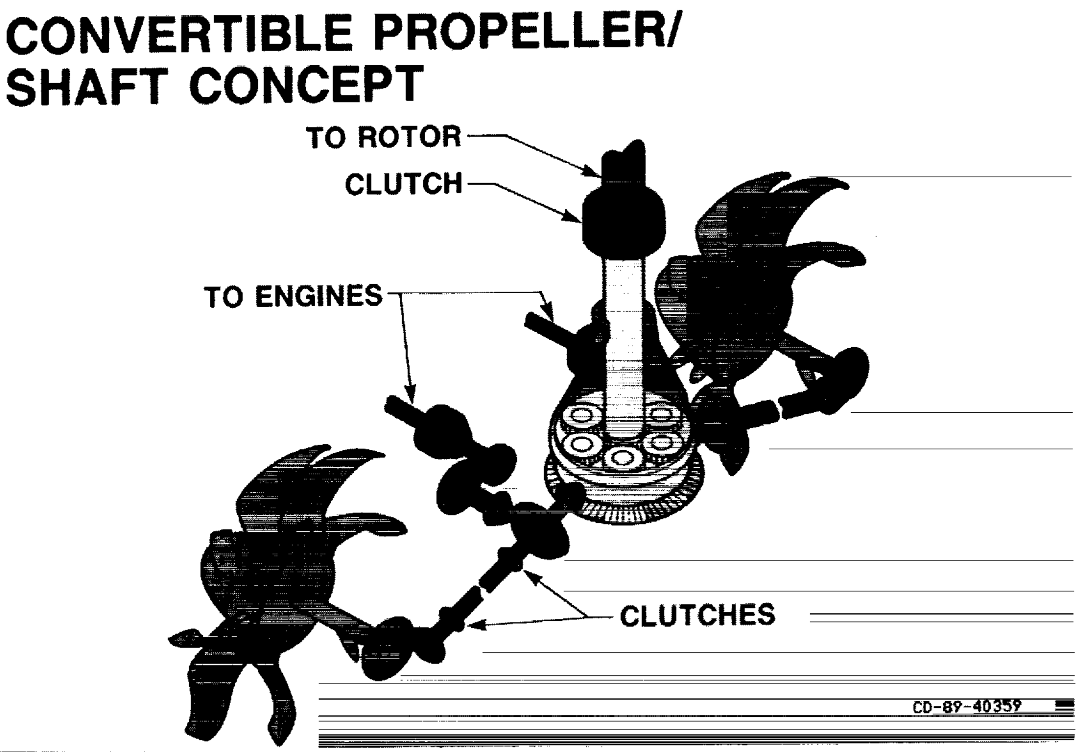

Figure 7. EXAMPLE OF SHAFT / CLUTCH SYSTEM WITH PROPULSORS REMOTE FROM ENGINES

CURRENT STUDIES

RATIONALE FOR CURRENT STUDIES

As noted above, convertible engine studies have been made, the results being published in 1982. In addition, a VIGV engine was built and ground tested at the Lewis Research Center in that same time period (references 4 and 5). However, the technology level used in the studies is now about a decade old, and the ground tests were made using a General Electric TF 34 core which dates back to the 1960's. Although the tests were successful and the viability of the VIGV concept proved, some additional technology work was deemed necessary. For the torque converter, which would be a magnitude greater in torque and power transmission than any built, no technology work has been done. Similarly, no new work has been accomplished for any of the other concepts in the last several years.

In order to have satisfactory propulsion information available for a 1990 high speed rotor craft study, new studies were obviously necessary. The goals of these current studies are divided into three parts.

1. Evaluate all conceivable convertible low spool systems based on technology that is foreseen as available by the year 2000.

2. Combine these low-spool systems with 1989 gas generator technology.

3. Combine these low-spool systems with high pressure, high temperature cores, envisioned for applicability post year 2005, roughly the DOD/NASA IHPTET (GEN6) goals with uncooled turbines at inlet temperatures possibly as high as 2500°F and appropriately high overall compression ratios.

These studies discussed herein address the first two goals. The third goal plus detailed layouts of engines of choice and a suggested technology program are candidate issues for possible future studies.

PRECURSOR STUDY TASKS

These precursor studies were executed by General Electric at their Lynn, Massachusetts facility, and by Allison Gas Turbine Division of General Motors Corporation. In order to expedite the work timewise and limit the costs, the contractors were allowed some latitude based upon their immediate capability. The study objectives are presented in Table I.

Table I

NASA PRECURSOR CONVERTIBLE ENGINE STUDIES

OBJECTIVES

- SCREEN & SELECT ADVANCED ENGINE CONCEPTS USING CURRENT TECHNOLOGY CORES
  - High Speed Applications (400 + kts.)
  - Cruise Thrust Only Applications
  - Cruise Thrust / Power (Dual-Mode) Applications
- PROVIDE DATA PACKAGES TO AMES AIRFRAME CONTRACTORS
- RECOMMEND FOLLOW-ON STUDIES

CONTRACTORS

- ALLISON GAS TURBINE
- GENERAL ELECTRIC

ENGINE SIZE AND MISSIONS

The engine sizes, 4000 and 8000 horse power, were motivated by the three Ames HSRC missions presented in table II. Note that two missions require a 6000 lb. payload and ranges of 600 and 700 nautical miles. The third has a 3000 lb. payload with a 350 mile range and additional attack time. For Allison the current gas generator technology is represented by a hypothetical upgrade beyond that of the current Allison 406. General Electric represents this technology with a growth version of the GE38 core with year 2000 Initial Operational Capability (IOC).

Table II

AMES HIGH SPEED ROTORCRAFT MISSIONS

- GROUND ATTACK MISSION
  - 3000 lb. Payload
  - 5370 lb. Fixed Weight
  - 270 Knots
  - 350 Mile Range
  - 17 Min OGE Hover
  - 4000 ft. Altitude
- MILITARY TRANSPORT MISSION
  - 6000 lb. Payload
  - 6370 lb. Fixed Weight
  - 450 Knots
  - 350 Mile Radius (700 Mile Total)
  - 16 Min. OGE Hover
- CIVIL TRANSPORT MISSION
  - 6000 lb. Payload
  - 5425 lb. Fixed Weight
  - 450 Knots
  - 600 Mile Range
  - 2 Min. OGE Hover

CONVERTIBLE ENGINE SCREENING CRITERIA

Table III lists those engine screening criteria used by the two engine companies. There are eight criteria (the most important) that are common to both GE and AGT.

Table III
CONVERTIBLE ENGINE SCREENING CRITERIA

<table>
<tr><th>GE</th><th>AGT</th></tr>
<tr><td colspan="2">• PERFORMANCE
• INSTALLATION
• WEIGHT
• SIZE
• DIMENSIONS
• COST
• RELIABILITY
• MAINTAINABILITY</td></tr>
<tr><td>• SAFETY
• VULNERABILITY
• INFRARED, RADAR CROSSECTION
• NOISE
• DIRT / BIRD INGESTION
• DISTORTION TOLERANCE
• DEVELOPMENT NEEDS
• TECHNICAL RISKS</td><td>• POLLED EXPERTS
AGT
3 AIRFRAMERS</td></tr>
</table>

CONCEPTS SCREENED

The broad choices of convertible engine concepts is presented in Table IV.

Both GE and Allison (AGT) examined clutched fans, VIGV systems, variable pitch fans and propfans. GE examined a pusher propfan as well as a tractor type and a remote fan. Allison examined a magnetic clutch in addition to a torque converter, a single rotation propfan in addition to counter rotation, a variable duct, directed air system, and an unswept turboprop.

Table IV

CANDIDATE CONVERTIBLE ENGINE CONCEPTS

GE

- CLUTCHED FAN
  - TORQUE CONVERTER
- VIGV
  - TIP SPAN
- VARIABLE PITCH FAN
- PROPFAN - TRACTOR
  - GEARED COUNTER-ROTATION
- PROPFAN - PUSHER
  - GEARED COUNTER-ROTATION
- REMOTE FAN

AGT

- CLUTCHED FAN
  - TORQUE CONVERTER
  - MAGNETIC CLUTCH
- VIGV
  - FULL SPAN
  - TIP SPAN
- VARIABLE PITCH FAN
- PROPFAN - TRACTOR
  - GEARED COUNTER-ROTATION
  - GEARED SINGLE ROTATION
- FAN WITH VARIABLE DUCT
- TURBOPROP (UNSWEPT)

SYSTEMS ELIMINATED IN INITIAL SCREENING

Table V presents a list of the systems eliminated in the initial screening.

General Electric dropped three of the systems in the initial screening without detailed examination: the remote fan, tractor propfan, and the variable pitch fan. The remote clutched fan offered few advantages over the clutched fan, but added the weight of shafting and a second nacelle. In addition, the loss of fan supercharging would be detrimental to fuel consumption. The tractor propfan appeared heavier and larger than the pusher propfan with no major offsetting advantages. It was felt that the variable pitch fan would require a low pressure ratio combined with a high bypass ratio resulting in a very heavy system with no advantage over the pusher concept.

There were four concepts eliminated without detailed examination by Allison Gas Turbine. In the initial screening it was determined that the magnetic clutch would be heavy, very complex and power consuming. Further, heat generation would require a cooling system. It was also determined that the variable duct system simply could not produce enough power for vertical lift, unless very oversized. The full span VIGV system was heavier and more complex with no appreciable improvement appearing possible. The non-swept turboprop, not surprisingly, was eliminated due to low propeller efficiency at speeds over 400 knots.

Table V

SYSTEMS ELIMINATED IN INITIAL SCREENINGS

GE		AGT	
Concept	Disadvantages	Concept	Disadvantages
• REMOTE FAN	• NO CORE SUPERCHARG. • WEIGHT	• MAGNETICALLY CLUTCHED FAN	• WEIGHT • HEAT GENERATION
• PROPFAN - TRACTOR	SYSTEM WEIGHT / SIZE • HEAVY GEARBOX, etc. • LONG ENGINE	• FAN WITH VARIABLE DUCT	INSUFFICIENT LIFT POWER
• VARIABLE PITCH FAN	1.3 PR LIMIT • SIZE • WEIGHT	• VIGV FULL SPAN	SPLIT SPAN VANES • COMPLEXITY • WEIGHT
		• TURBOPROP (UNSWEPT)	LOW THRUST AT HIGH SPEED

CONCEPTS FOR FINAL SCREENING

Both engine companies determined that in the 4000 to 8000 horsepower range, the technical differences would be small and, with the exception of sizing limitations, could be ignored. This simplified the screening task.

The mission calculations for both contractors were based upon the Fold Tilt Rotor concept. Since the Ames sponsored studies were just being initiated, no guidance as to aircraft type was available. Thus, the choice was based essentially on the availability of aircraft data, the tilt rotor being a developed and flying vehicle.

Figures 8 and 9 present pictorially the concepts that were carried into detailed screening by General Electric and Allison, respectively. For GE, these were the geared UDF pusher (propfan), the clutched fan (torque converter), and the VIGV fan. For Allison there were five concepts carried into the detailed screening. These were the clutched fan (torque converter), the VIGV (tip span), the variable pitch fan, and the tractor propfan with both single and counter rotation.

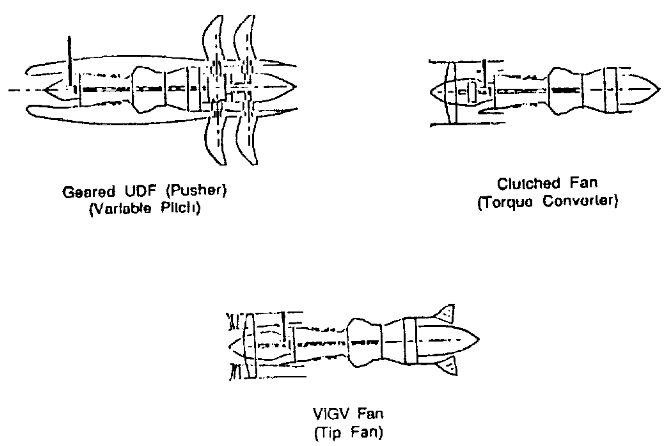

Figure 8. GENERAL ELECTRIC CONCEPTS FOR MISSION ASSESSMENT

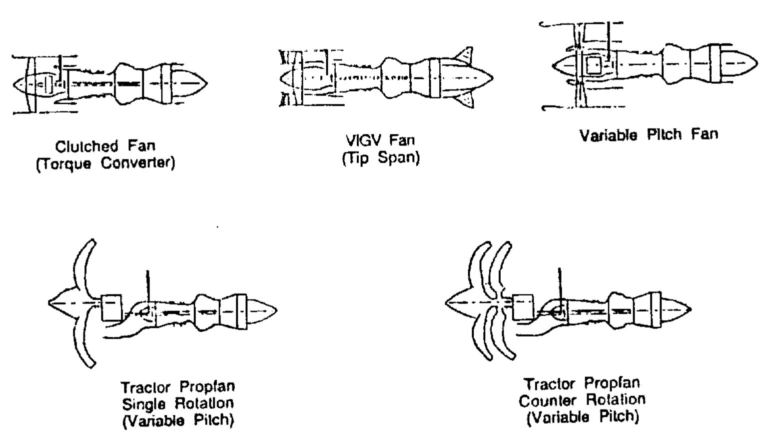

Figure 9. ALLISON CHOICES FOR DETAILED SCREENING

GENERAL ELECTRIC SELECTION RATIONALE

Table VI lists the advantages and disadvantages or areas of concern of the three choices of General Electric.

The geared UDF in the pusher mode is excellent in both weight and fuel consumption. It is well suited to dual-mode operation. However, the complexity is high. The large propfan diameter makes installation difficult. Furthermore, there are the several concerns noted regarding its use on military aircraft.

The clutched fan is compact with good installability characteristics. It has good hover SFC (simply a turboshaft engine), and at cruise it is a standard turbofan engine with supercharging. However, no practical method for long duration dual-mode operation is foreseen. This would appear to obviate its use for an X-wing type aircraft. Also, the availability of such a torque converter is uncertain.

The VIGV offers many of the advantages of the clutched fan. In addition, a great deal of technology work has been done on this system. It is a concept that offers simple, long duration dual-mode operation. However, due to churning with the guide vanes closed, the hover SFC is exceedingly high. Noise and material stresses may also be a problem.

Table VI

GENERAL ELECTRIC CHOSEN ENGINES

	ADVANTAGES	DISADVANTAGES
PROPFAN (PUSHER) (GEARED UDF®)	• EXCELLENT THRUST SFC • BEST HOVER SFC • THRUST CANCELLATION / REVERSAL • GOOD SPLIT POWER OPERATION	• COMPLEX, EXPENSIVE • LARGE DIAMETER PROPFAN • VULNERABLE PROPFAN • NOISE, RADAR CROSS-SECTION (PROPFAN) • DIFFICULT INSTALLATION • PERSONNEL SAFETY
CLUTCHED FAN	• SUPERCHARGED AT CRUISE • LIGHT WEIGHT • MOST COMPACT • GOOD HOVER SFC • GOOD INSTALLABILITY	• TORQUE CONVERTER ADDS COMPLEXITY MAINTENANCE • POOR STEADY STATE POWER SPLIT • RESIDUAL THRUST
VIGV	• SIMPLEST • GOOD SPLIT POWER OPERATION • LEAST EXPENSIVE • GOOD INSTALLABILITY	• CLOSED IGV OPERATION YIELDS NOISE, STRESSES, HIGH WINDAGE • HIGH RESIDUAL THRUST • POOR HOVER SFC

ALLISON GAS TURBINE SELECTION RATIONALE

Allison Gas Turbine used a scoring system to show the relative virtues of several engine parameters ranging from SFC to cost. The best rating is 1 with the scoring ranging to a poorest rating of 10.

Table VII shows the results of this evaluation, and from it the advantages and disadvantages of the several systems can be observed. The propfans are limited by weight, size and maintainability, although excellent in SFC. The clutched fan using a torque converter has the lowest (best) score. Although its cruise SFC cannot compare to the propfans, it is well rated in other aspects. The VIGV concepts suffers mainly in SFC and residual thrust. Due to the churning problem, its hover SFC is definitely on the high side. The 1.3 pressure ratio variable pitch fan, with its large diameter, suffers mainly in the size and weight area with maintainability some problem. The 1.6 pressure ratio V.P. fan, however, offers a much smaller size and weight penalty, according to Allison Gas Turbine, and it has an excellent score. The three top rated, then, are the torque converter concept first, followed by the variable pitch fan with the 1.6 pressure ratio, and third, the VIGV.

It must be pointed out again regarding the leading system that the torque converter itself does not exist. In the case of the 1.6 pressure ratio variable pitch fan, it should be noted that such a fan has never been built in this size and pressure ratio. The VIGV system appears to be the closest to ready technologically.

Table VII

ALLISON NUMERICAL SCREENING

Convertible Engine Ranking *

	CONVERTIBLE ENGINE CONCEPT					
	PROPFAN			TURBOFAN		
SFC	Counter Rotation	Single Rotation	Torque Converter	Tip VIGV	Variable Pitch Fan $Rc_F=1.3$	$Rc_F=1.6$
CRUISE	1	2	5	5	3	4
HOVER	1	1	1	5	4	3
WEIGHT	$\boxed{10}$	$\boxed{9}$	3	2	5	1
COST	5	4	1	1	3	2
SIZE	$\boxed{8}$	$\boxed{10}$	1	2	$\boxed{6}$	1
INSTALLATION	3	3	1	1	2	1
MAINTAINABILITY	5	3	2	1	3	2
RELIABILITY	4	3	1	1	3	2
RESIDUAL THRUST	1	1	2	$\boxed{6}$	5	4
TOTAL	38	36	17	24	34	20
ORDER OF RANKING	6	5	1	3	4	2

* RELATIVE SCALE 1-BEST

AIRFRAMER COMMENTS ON ALLISON CONCEPTS

A similar qualitative evaluation was done by several airframers. Essentially the areas of concern are the same as those recognized by Allison and the top three choices are the same as Allison's.

Table VIII presents the airframers summary comments. Here clear choices for the clutched fan and the variable pitch fan are declared. The most interesting comment, however, is that stating an interest in a combined variable pitch/clutched fan system, one that had not been addressed in these precursor studies. Investigation of such a system must be relegated to a follow-on study.

Table VIII

AIRFRAMER COMMENTS ON ALLISON CONCEPTS

- CLUTCHED FAN:
  - LOW GYROSCOPIC FORCES
  - NO RESIDUAL FAN THRUST
  - BEST HOVER SFC
  - NO FAN EROSION
- VARIABLE PITCH FAN:
  - ACCELERATION RESPONSE
  - GOOD THRUST MODULATION DURING TRANSITION
- BEST CONVERTIBLE SYSTEM MAY BE A COMBINATION OF TORQUE CONVERTER WITH VARIABLE PITCH FAN

COMPARISON OF RESULTS

COMPARATIVE ENGINE WEIGHTS

The comparative weights of the three GE and five Allison engines are presented in figure 10. The weights are given as specific weights in pounds per horsepower.

First, the similarities will be noted. The torque converter systems are seen to be about the same in total weight. GE and Allison both computed the weight of the torque converter as roughly ten percent of the engine weight. The tip VIGV systems are also similar in total weight. Both contractors computed additional weight for this system above that of a turbofan to be about 15 percent.

The other results indicate major differences between GE and Allison. It is seen that the propfan (or geared UDF) findings differ greatly between GE and Allison. The GE results show that by using the pusher prop and simply employing an epicyclic gear system adjacent to the hot section, a light weight system results. Allison only investigated tractor type systems with a gearbox remote from the turbines. Their results indicate weights 60% higher than those of competing systems due to propulsor and gearing. GE shows these subsystems to make up about 40% of the total engine weight while Allison shows them to be about 60% of the total weight. This difference will have to be substantiated in more detailed future studies.

The variable pitch fan results offer an equally dichotomous situation. General Electric in the very first part of its screening estimated that a variable pitch fan would be very heavy and impractical. The Allison study suggests that this fan would be lighter than the clutched fan and roughly equal in weight to the VIGV system. The reason for this difference can only be understood and reconciled by doing a more detailed design. This too, will have to wait for an additional effort.

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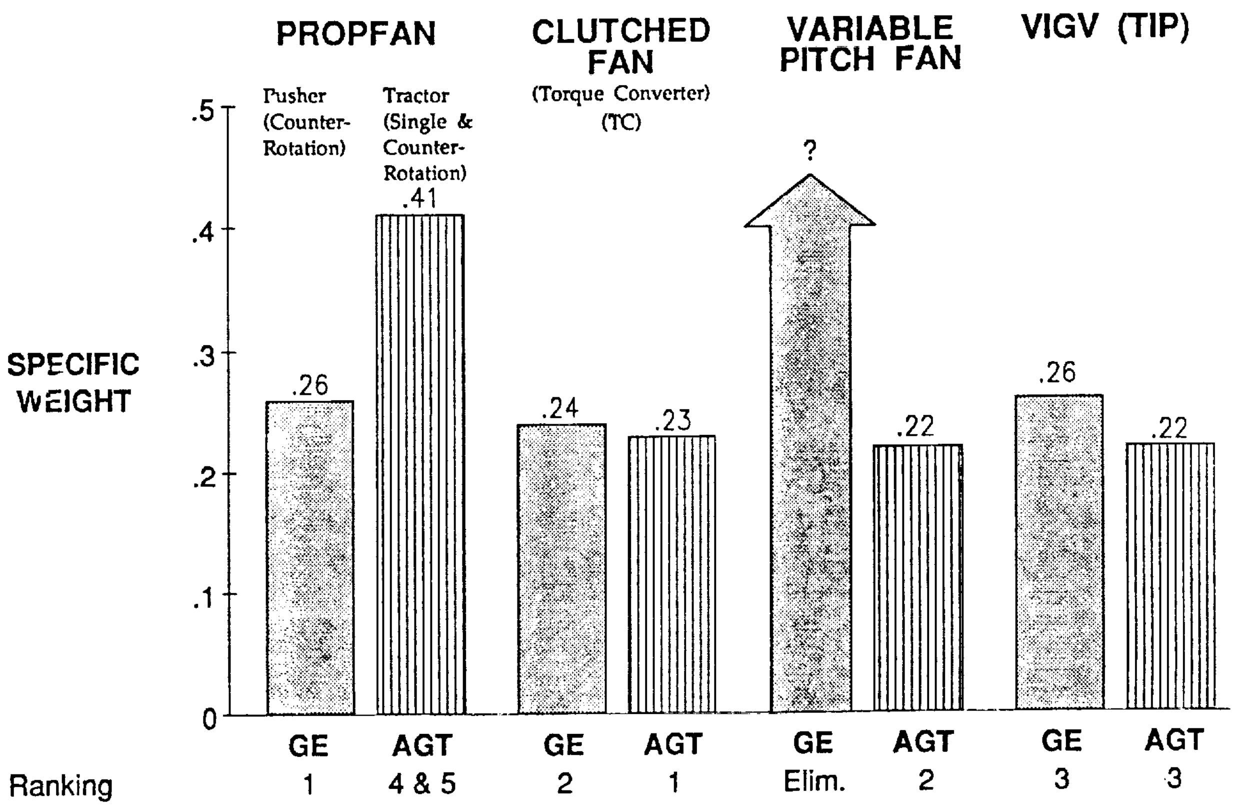

Figure 10. CONVERTIBLE ENGINE SPECIFIC WEIGHTS
(Pounds Per Horsepower At Sea Level)

COMPARATIVE MISSION RESULTS

Table IX shows results for the three missions GE examined. Here, GE completed the missions, but the payload fractions were allowed to decrease. Note that none of the available payload fractions came anywhere near that required. Substantial aircraft size increases would be needed to satisfy the mission requirements. As an example, utilizing the engine having the lowest weight and SFC, the geared propfan configuration, the aircraft for the civil transport mission would have an estimated takeoff gross weight of 47200 lb., nearly double their 25000 base aircraft.

Allison shows similar results for a hypothetical four hour mission, which is shown in table X. The mission can easily be completed (with the exception of hover capability) with non-convertible turbofan engines. Plenty of reserve fuel is available. For the same takeoff gross weight (TOGW), the mission can barely be completed using the preferred convertible systems, with no reserve fuel capacity. For other contending systems, the mission could not be completed. Of course, if the TOGW were allowed to rise considerably, the mission could be completed.

What all of this indicates is the fact that if a viable high speed rotorcraft is to come to fruition, serious effort must be made to reduce the empty weight of the aircraft. This very much includes the propulsion system, and methods to do this must be addressed in future work.

Table IX

GENERAL ELECTRIC MISSION SUMMARY

Rotorcraft Weight Fractions
Fixed 25000 lb. TOGW

MISSION	GROUND ATTACK			MILITARY TRANSPORT			CIVIL TRANSPORT		
CONVERTIBLE ENGINE TYPE	Clutched Fan	VIGV	UDF	Clutched Fan	VIGV	UDF	Clutched Fan	VIGV	UDF
EMPTY WEIGHT FRAC.	.750	.777	.745	.770	.790	.775	.766	.786	.771
FUEL WEIGHT FRAC.	.237	.278	.188	.280	.303	.218	.208	.201	.150
AVAILABLE PAYLOAD FRAC.	.013	-.055	.067	-.050	-.093	.007	.016	.013	.079
REQUIRED PAYLOAD FRAC.	.120	.120	.120	.240	.240	.240	.240	.240	.240

Table X

ALLISON MISSION SUMMARY

MISSION: 500 MILE RADIUS
2 HR LOITER
15 MINUTES HOVER
PAYLOAD 1200 LBS.
TOGW 22000 LBS. (FIXED)

4.2 HOURS DURATION REQUIRED (WITHOUT RESERVES)

PROPULSION	DURATION (HOURS)
TURBOFAN BASE (CTOL)	5
CLUTCHED FAN (TORQUE CONV.)	4.25
VARIABLE PITCH FAN (R_C 1.6)	4.20
TIP VIGV	4.20
VARIABLE PITCH FAN (R_C 1.3)	3.50
PROPFAN COUNT. ROT.	2.60
PROPFAN SING. ROT	2.40

CONFIGURATION OF PREFERRED ENGINES

Figure 11 presents pictorially the engine configurations of choice for GE and Allison, respectively. These engines, as noted before, use current technology cores (essentially updated existing engines) and, thus, no great surprises are in evidence. The differences between them are in the turbofan sizing. GE's work resulted in bypass ratios of between 4 and 5 with fan pressure ratios of about 1.7. Allison's engines all have a 1.6 fan pressure ratios with bypass ratios of 6.

In actuality, determining the best configuration for these engines will require a more detailed study in conjunction with the airframe companies. Installation, complexity, and drag will have to be given careful consideration along with weight and SFC. Further, if high pressure ratio, high temperature cores are possible, this could totally change engine configurations. This all has yet to be ascertained.

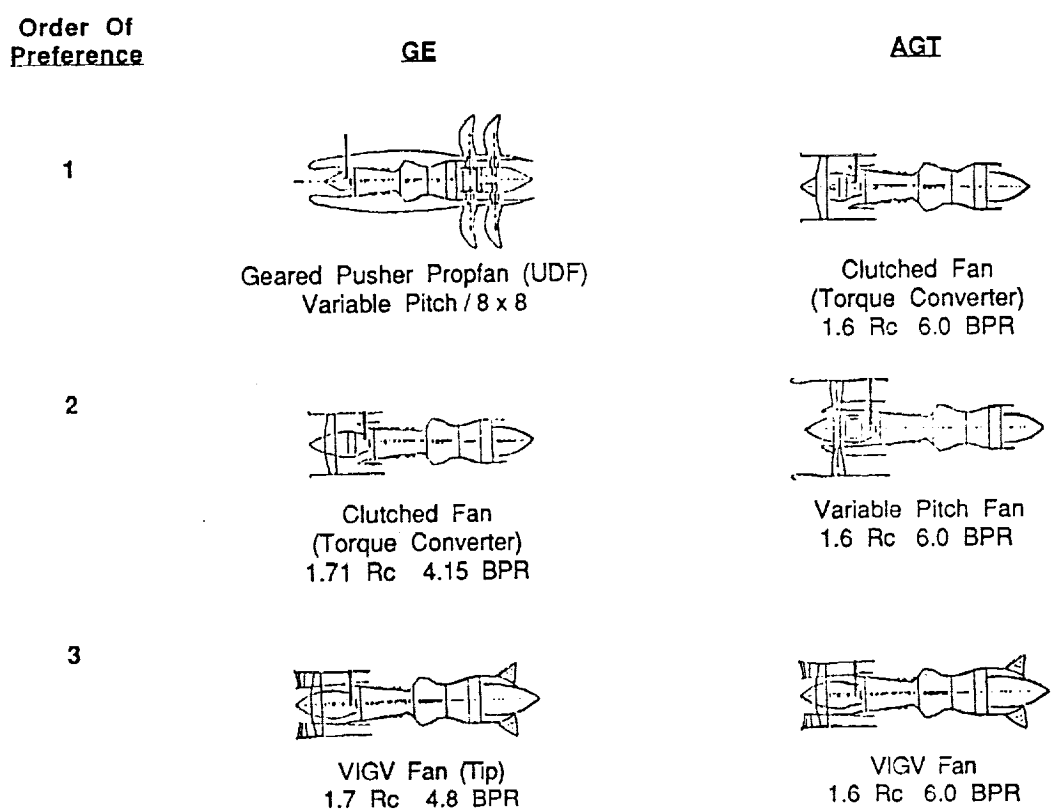

Figure 11. PREFERRED CONVERTIBLE ENGINES

REQUIRED FOLLOW-ON EFFORTS

Table XI lists the follow-on work deemed necessary by GE and Allison. It also includes areas requiring investigation that became evident to NASA due to the differences in results of the two studies.

As noted previously, preliminary data packages have been prepared for the airframe companies performing the Ames sponsored studies. Efforts must be made in two areas as the Ames studies move ahead. The engine data will have to be specifically tailored to the various requirements of the airframes of choice. Too, dichotomies encountered in assessing the propfan and the variable pitch fan will have to be addressed. Both of these needs require design work well beyond the scope of these precursor studies.

As seen from the mission studies, HSRCs with current airframe and engine technology would be quite heavy aircraft for a given mission. This suggests more advanced technology would be fruitful. For engines, this means utilizing the high pressure ratio, high temperature cores, with technology resulting from other programs. The impact on convertible engines will have to be determined, and useful data packages for use by the airframers will have to be prepared.

The advanced technology plan is a real necessity. No convertible engine exists. True, technology work has been done and proof of concept of both VIGV systems and small variable pitch fan systems has been proved. However, both systems still require more technology effort. For example, the VIGV operation with the guide vanes closed presents a severe efficiency loss, which would be a problem for some aircraft in hover mode.

Table XI
PROPOSED FOLLOW-ON CONVERTIBLE ENGINE STUDIES

- ENHANCE PRECURSOR STUDIES
  - INCORPORATE AIRFRAMER REQUIREMENTS
  - DETAILED ASSESSMENT OF VP FAN (FPR ~ 1.6)
  - FEASIBILITY ASSESSMENT OF PROPFAN (UDF) WITH GEARBOX ADJACENT TO HOT SECTION
- ASSESS IMPACT OF ADVANCED CORE TECHNOLOGY
  - GENERATE YEAR 2010 IOC ENGINE DATA PACKS
- RECOMMEND ADVANCED TECHNOLOGY PLAN

PRELIMINARY TECHNOLOGY REQUIREMENTS

Although not a goal of these study efforts, some future technology requirements have surfaced and are listed in Table XII. The torque converter clutched turbofan has been chosen by both companies as an excellent convertible engine candidate. As noted before, no device exists in the size required. If dual-mode operation is required at cruise, an engine considered a candidate by both companies is the VIGV concept. This system, too, has never been carried to a point where adequate design methods are available. Also, it has a serious power loss when operated in the closed guide vane configuration.

Table XII

PRELIMINARY LIST OF TECHNOLOGY REQUIREMENTS

- 8000 H.P. TORQUE CONVERTER DATA BASE
- DESIGN DATA BASE FOR EFFICIENT VIGV FANS
- INVESTIGATE CHURNING LOSS MINIMIZATION DURING CLOSED VIGV OPERATION

CONCLUDING REMARKS

The goals of these studies have been met. Table XIII sums up what has been achieved in these study efforts. The major portion of the work was, of course, the choosing of the candidate engines with current core technology. The preparation of data packages for, and offers of cooperation with, the Ames airframers have been accomplished. In addition, plans for a more detailed follow-on effort have been put forward. True, some questions have surfaced, but this only helps to better determine the areas of uncertainty that must yet be addressed.

Table XIII

SUMMARY OF STUDY ATTAINMENTS

- CHOICE OF CANDIDATE CONVERTIBLE ENGINES (CURRENT TECHNOLOGY CORES)
- DATA PACKAGES FOR AIRFRAMERS
- REQUIRED FOLLOW-ON EFFORTS

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15. Supplementary Notes

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16. Abstract

Two NASA-Lewis sponsored studies were conducted to determine the most promising convertible engine concepts for high speed rotorcraft. These precursor studies projected year 2000 convertible technology, but were limited to current gas generator technology. The impetus behind these efforts was to insure that appropriate propulsion information would be available for the contracted High Speed Rotorcraft studies being conducted under the aegis of the NASA Ames Research Center. In this presentation, the efforts of General Electric and Allison Gas Turbine are described. Propulsion systems were investigated for use on aircraft requiring thrust only at cruise and those aircraft requiring both power and thrust at cruise. The aircraft and missions used for the comparisons are presented. The methods for engine selection and the basic characteristics of the selected engines are also presented. Differences in engines selected by the two contractors are explained. In addition, the technology needs are identified along with suggested plans for more detailed follow-on studies, including those that address the use of high temperature, high pressure ratio gas generators utilizing technology expected to be available beyond year 2005.

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